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THESIS

AN ANALYSIS OF THE TACTICAL UNMANNED VEHICLE LIGHT DURING URBAN COMBAT OPERATIONS USING THE JANUS COMBAT MODEL

by

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March 1999

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ABSTRACT

The shift of the world's population to the cities has caused the military to increase its focus on urban terrain. The same Tactics, Techniques, and Procedures that are effective on an unconstrained battlefield are not effective in an urban environment. Using technological advances, it may be possible to replace flesh and blood soldiers and marines with metal and plastic surrogates to perform the Reconnaissance, Surveillance, and Target Acquisition mission. Since these unmanned vehicles and the tactics to employ them are still in the concept development phase, they are not widely tested yet for their utility in tactical scenarios. This thesis will examine the detection capability and survivability of a Tactical Unmanned Vehicle Light in an urban environment. The data is generated through multiple combat simulations using the Janus combat model and is analyzed using statistical techniques. The result benefits the Unmanned Ground Vehicle/System Joint Project Office in their acquisition process and both the United States Army and Marine Corps in their development of Tactics, Techniques, and Procedures for employment of unmanned tactical systems in urban warfare.

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LIST OF SYMBOLS, ACRONYMS, AND/OR ABBREVIATIONS

α	Level of significance
μ	Mean
ν	Adjusted Degrees of Freedom
σ^2	Variance
S_p	Pooled Estimate of Variance
TS	Test Statistic
AAAV	Advanced Amphibious Assault Vehicle
ANOVA	Analysis of Variance
AWE	Advanced Warfighting Experiment
C4I	Command, Control, Communications, Computers, and Intelligence
CDF	Cumulative Distribution Function
DoD	Department of Defense
ECOC	Experimental Combat Operations Center
IPB	Intelligence Preparation of the Battlefield
JCATS	Joint Conflict And Tactical Simulation
JPO	Joint Project Office
KS	Kolmogorov-Smirnov
LAR	Light Armored Reconnaissance
LAV	Light Armored Vehicle
LOS	Line of Sight
ME	Moving, Exposed
MEF	Marine Expeditionary Force

MEU	Marine Expeditionary Unit
MOE	Measure of Effectiveness
NPS	Naval Postgraduate School
Ph	Probability of Hit
Pk	Probability of Kill
RF	Radio Frequency
RSTA	Reconnaissance, Surveillance, and Target Acquisition
SARGE	Surveillance And Reconnaissance Ground Equipment
SD	Stationary, Defilade
STV	Surrogate Teleoperated Vehicle
TMAP	Teleoperated Mobile All-purpose Platform
TTP	Tactics, Techniques, and Procedures
TUV	Tactical Unmanned Vehicle
TUVL	Tactical Unmanned Vehicle Light
UA	User Appraisal
UGV/S	Unmanned Ground Vehicle/Systems

EXECUTIVE SUMMARY

The rise in population in urban regions has caused the United States military to put more emphasis on the development of doctrine, training, and equipment for military use in urban operations. The urban environment is extremely taxing on manpower. Using technological advances, it may be possible to replace flesh and blood soldiers and marines with metal and plastic surrogates that perform some of the same missions. Unmanned Ground Vehicles (UGV) are an example of this technology. Placing a video camera on a vehicle, controlling it remotely by radio signal or fiber optic cable, and driving that vehicle into situations that would normally be unsuitable for a person may enable the commander to fulfill a Reconnaissance, Surveillance, and Target Acquisition mission without putting troops in harm's way. This thesis explores the detection capability and survivability of a notional UGV called a Tactical Unmanned Vehicle Light (TUVL) in an urban environment.

The underlying political-military situation, on which this thesis is based, is that social unrest and genocide in a foreign coastal city has attracted the attention of the U.S. A Marine Expeditionary Unit is deployed to evacuate U.S. citizens and to restore order to the region. The marines will land in two phases, one by air and one by way of amphibious vehicles. The mission of the amphibious landing is to clear and secure a portion of the city for follow-on forces. A TUVL is used by each squad in this force to gain information on enemy disposition. Deployment of forces is based on the information the TUVL passes on to the commander.

The high resolution combat model, Janus version 6.88, is used to model the performance of the TUVL against an enemy force of riflemen. The terrain used in the

model is representative of the Naval Postgraduate School in Monterey, CA. The terrain is populated with 54 opposing riflemen. There are six TUVLs which will move in each zone, along designated routes in order to detect enemy riflemen. The riflemen can detect and attack the TUVL. The Janus post-processor records each direct fire and detection event in chronological order. Four Measures of Effectiveness (MOE) are used to examine the detection capability of the TUVL and survivability of the TUVL. These MOEs are the average detection range for a moving, exposed TUVL, detecting riflemen in varying movement status, the average detection range of the TUVL detecting riflemen in each zone, the number of riflemen detected by the TUVLs, and finally, the proportion of total shots taken by the riflemen that impact on the TUVL.

The analysis of the data reveals that there is a difference between the mean detection range of a Moving-Exposed TUVL detecting a Moving-Exposed Riflemen and a TUVL detecting a Stationary-Defilade Riflemen. Also, the effect of terrain on differences in the average detection range between two pairs of TUVL systems need further evaluation. Terrain affects the number of detections that the TUVL can make. Finally, the analysis uncovered that there is no difference between the proportion of frontal shots that kill a TUVL and the proportion of flanking shots that kill a TUVL.

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I. INTRODUCTION

A. OVERVIEW

1. New Emphasis on Urban Operations

The dominant demographic trends of our time are the population flight from the interior to the coast and from rural to urban areas. This will lead to the appearance of threats in the world's littoral regions, those areas within 300 miles of the coast. [Ref. 1:p. 5] Population models estimate that 70% of the world's population will live in cities by the year 2020. Seventy percent of these cities will be located on the world's littorals. [Ref. 2:p. 4] This shift to the cities has caused the military to increase its focus on urban warfare and to develop new ways to conduct operations in urban terrain. The same Tactics, Techniques, and Procedures (TTP) that are effective on an unconstrained battlefield are not as effective in an urban environment.

2. Urban Combat Characteristics

The urban environment is characterized by several attributes that are not present on the open, unconstrained battlefield. Operations can exist on a combination of planes different from those that exist on an open battlefield:

- Subterranean plane using sewers and subways
- Surface plane using floors of the urban canyons
- Structural plane from building to building
- Air above the city [Ref.3:p. 4]

Additionally, the structures that populate a city will limit large scale use of indirect fire assets such as naval surface fire support, close air support, artillery and mortars. Also, the density of structures hampers communication between units even over very short

distances. The industrial infrastructure produces smog that reduce sensor performance. Combat operations in built-up areas favor the defender and require vast amounts of small arms ammunition and grenades. Lastly, precise positioning of units and weapons fires is necessary to reduce the possibility of catastrophic fires or non-combatant casualties.

3. Scope of Thesis

Using technological advances it may be possible to replace flesh and blood soldiers and marines with metal and plastic surrogates that perform some of the same missions. This replacement should not only reduce casualties but also should allow the commander to utilize his forces more efficiently. The Unmanned Ground Vehicle/System Joint Project Office (UGV/S JPO) deals with these issues as the U.S. Army's and U.S. Marine Corps' acquisition proponent for unmanned ground systems. The UGV/S JPO is tasked by the Department of Defense with developing unmanned ground systems for tactical purposes. The U.S. Army has expressed interest in a UGV/S that is man-packable by three soldiers to fulfill the Reconnaissance, Surveillance and Target Acquisition (RSTA) mission in an urban setting. It is the responsibility of the UGV/S JPO to lead the acquisition process for systems that fall into this category.

At this point in the acquisition process, decisions need to be made concerning methods of employment, detection capability of the system components, counter-detection and survivability. There are trade-offs that must be examined. A small system is harder to detect by the enemy, but on the other hand it may not detect the enemy because of intervening obstacles that block the system's line-of-sight (LOS). If the system contains the most technologically advanced components, but is easily detected and killed, then funds are wasted. In an urban setting, the maximum detected distances of

sensors are reduced; hence, an increased sensor capability may not show an advantage. It is assumed that the systems will become targets since these unmanned systems may operate out of the defensive perimeter of soldiers and marines and within close proximity to the enemy. Therefore, a disposable system should be considered. Thus, this thesis examines the survivability and detection capability of a system in the given scenario. For the purpose of this process, this thesis defines a UGV/S conducting the RSTA mission as a Tactical Unmanned Vehicle Light (TUVL).

B. BACKGROUND

1. Unmanned Ground Vehicle/Systems Joint Project Office

a. Formation of the UGV/S JPO

The UGV/S JPO was formed in 1988 by the Department of Defense (DoD) in order to consolidate the UGV/S efforts and resources of both the U.S. Army and the U.S. Marine Corps. Industry produced several unmanned systems during the following years. The first two versions of the Teleoperated Mobile All-purpose Platform (TMAP) were developed but not accepted by the military. Following this, the Surrogate Teleoperated Vehicle (STV), the next generation of teleoperated vehicles, was rejected due to problems with stability and communications. Then, Sandia Laboratory developed 'Dixie'. The Army had planned to examine Dixie in the program's sixth year, but Sandia had subsequently built an improvement based on a Yamaha Breeze all-terrain vehicle. This improvement was named the Surveillance And Reconnaissance Ground Equipment (SARGE). The UGV/S JPO contracted SUMMA Technologies, Inc. to build the SARGE units, with Sandia operating as technical advisor. [Ref. 4] The SARGE was then scheduled for field testing by U. S. Army ground combat units.

b. User appraisal objectives

In June 1996 a Memorandum of Agreement was signed between the UGV/S JPO, the U.S. Army's 3d Brigade, 3d Infantry Division (Mechanized) and 2-69 Armor Battalion to conduct a User Appraisal (UA) for the TUV. Four SARGE systems were released to Scout Platoon, 2-69 Armor Battalion in January 1997. The UVG/S JPO defined five objectives for the TUV UA:

- Develop the Tactics, Techniques and Procedures (TTP) for the operational implementation of the TUV
- Recommend changes to the TUV Operational Requirements Document (ORD) based on user feedback
- Suggest changes to the TUV system performance specification
- Recommend design changes to improve reliability, maintenance and operational performance of the SARGE
- Gain insight into the potential operational effectiveness of the system

[Ref. 5]

c. User appraisal results

The results of the UA are promising to the prospect of utilizing unmanned systems for reconnaissance, targeting, surveillance and other missions. Both the scout platoon survivability and the number of areas that were physically observed increased. The SARGE enabled the scout platoon to expand the distance to which reconnaissance was conducted without the requirement for indirect fire support from the platoon's parent battalion. The scout platoon concluded that the TUV system made a positive contribution to the operational effectiveness of 2-69 Armor Battalion. [Ref. 5]

d. Shift to lighter vehicle

The size of the TUV system that was tested during the user appraisals was not a detriment to the system because the terrain was open with an unimpeded field of view. However, in an urban environment the size of that TUV would prevent it from being used inside buildings and other confined spaces. Furthermore, the structures present in an urban setting would reduce the maximum field of view of the TUV, thereby wasting funds on unused components. Therefore, the usefulness of a smaller, less expensive and possibly disposable version of the TUV must be explored.

2. Urban Warrior

a. Purpose

Urban Warrior is one of the Marine Corps Warfighting Laboratory's experimental phases. Each of the experimental phases is part of the Sea Dragon concept. The goal of Sea Dragon is to develop the technology and doctrine that is needed to meet threats in the 21st Century. In the spring of 1997, Hunter Warrior explored concepts in extended battlespace dominance using small dispersed units. Capable Warrior, Information Warrior, Coalition Warrior, and Future Warrior are experiments that will be conducted in the next decade. Urban Warrior explores the equipment, technologies, tactics and for urban combat in the future. The Laboratory states the Urban Warrior hypothesis as follows: [Ref.2]

> Can we significantly increase the ability of forward afloat forces to execute simultaneous, non-contiguous operations in both the extended and constrained urban battlefields to include:
> 1. Penetrating and operating in the dense urban battlefield.
> 2. Operating in critical areas of the extended battlefield on the approaches surrounding dense urban areas.
> 3. Dealing with weapons of mass destruction.
> 4. Seabasing the bulk of support capabilities including C4I and sustainment.

b. Phases

Urban Warrior will be conducted in two phases. The first phase was conducted on the East Coast through September 1998 using Second Marine Expeditionary Force (II MEF) elements with an emphasis on developing TTPs, and incorporating equipment and technology enhancements that improve urban operating capabilities. Another goal of the first phase was the development of a revised training program for operating in an urban environment. The second phase will be conducted during the October 1998 to Spring 1999 period on the West Coast using First Marine Expeditionary Force (I MEF) elements with an emphasis on applying the advanced urban warfare TTPs to seabased urban operations using the refined Experimental Combat Operations Center (ECOC). As part of the second phase, the Urban Warrior Advanced Warfighting Experiment (AWE) will be conducted on the West Coast by I MEF and 3d Fleet operating forces during March-April 1999 under the umbrella of the 1999 Kernal Blitz joint exercise. This AWE is the operational foundation on which this thesis is based.

c. Urban warfare tactics

New tactics are being developed in order to meet threats found in urban environments. "Urban Penetration" is a precise attack on a clearly defined terrain or enemy objective. "Urban Thrust" attacks the enemy along a narrow frontage, maximizing combat power at the point while defending the flanks. "Urban Convergence" is similar to a police response to a situation; dispersed patrolling units converge on a unit in contact. "Continuous Attack" is an around-the-clock offensive that uses a percentage of the force to apply relentless pressure on the enemy. This tactic

requires a rotation of units in contact through periods of rest and maintenance. "Continuous Attack" is characterized by surge operations with the entire force at a critical time and place. "Active Defense" is the merging of the tactics of coordinated, dispersed attack and the defense. This tactic confuses the enemy as to the location of defensive lines and critical vulnerabilities and dissipates enemy energy on non-critical areas. [Ref. 3:p. 10-16]

d. *Urban warfare phases*

Combat operations in an urban environment are conducted in five phases; preparation, isolation, penetration, exploitation, and consolidation/transition. There is not necessarily a distinct transition point between phases. One phase may instead fade into the next.

The preparation phase is characterized by Intelligence Preparation of the Battlefield (IPB) that may require some penetration of the urban setting by physical and electronic means. During the penetration portion of this phase maps are developed and information is gathered concerning utilities, transportation, building layout, and building construction materials. Once this information is gathered, the isolation phase begins.

The isolation phase is conducted using a variety of electronic, psychological, and physical assets. Electronic jamming, barriers (lethal and non-lethal), unmanned systems, indirect fires, conventional ground forces, and special operating forces can all be used to isolate people or areas. Communication centers, utilities, transportation routes, and groups of people (combatants and non-combatants) may all require isolation.

During the penetration phase, key nodes and penetration points are seized as necessary. Examples of these nodes are roof tops, transportation nodes and candidate landing zones. Two purposes of this phase are to interrupt the enemy's decision cycle, and to lower or destroy the enemy's ability to resist. This is the phase in which most fighting may occur and the phase in which the Urban Penetration, Urban Thrust or Urban Convergence tactics are used.

In the next phase, exploitation, friendly forces gain control of larger and larger areas. This happens in two ways; connect-the-dots and ink blot. The former is performed by establishing secure lines of communication between urban centers while the later is performed by ever increasing the area of control around a fixed point. In concert with the tactic of Continuous Attack, barriers, unmanned sensors, ground forces and indirect fires are used to achieve the goals of this phase.

The final phase of Consolidation and Transition defines a strategy that allows for the withdrawal of friendly forces. Although, other assets may be needed such as civil affairs units and infrastructure repair and maintenance teams. The goal is that city functions and government are returned to local authorities. [Ref. 6:p. 3-5]

C. OBJECTIVES

One of the objectives of an AWE is to explore the utility of emerging technologies during combat in the next century. The Marine Corps has experimented with the use of slippery and rigid foams for use as barriers. Another technology that has important uses in urban combat is "see through wall" technology. Unmanned systems, such as the TUVL, are also included in this group of advanced technologies that will shape TTPs in the future.

Many of these tactics are new. More training for urban combat is necessary to guarantee success in the next century. As the UA has shown [Ref. 5], unmanned systems are of benefit to operating forces in open terrain and contribute to the effectiveness of a scout platoon conducting the RSTA mission. Unmanned systems are an integral part of how the services will fight in the future. Modelling can help determine the best tactics and system characteristics for fighting with unmanned systems in urban settings.

The objective of this thesis is to examine the detection capability and survivability of one of these unmanned systems. The data concerning detection capability and survivability that is produced in this thesis by the Janus version 6.88 combat model, demonstrates that the model is a good representation of what is commonly expected of the TUVL performance in an urban environment. This model can be the basis for further analysis of other aspects of the employment of unmanned systems in urban terrain. This thesis expects to show that the average detection range of a TUVL is greater for a moving and exposed target than a stationary and concealed target. Furthermore, the author will show that the average detection range for a TUVL is very sensitive to the type of terrain in which it operates. The author expects that a TUVL becomes an easier target when firing comes from the side than from the front of the TUVL because of the smaller cross section available to the shooter. Finally, the terrain in which the TUVL operates is expected to have an impact on the proportion of enemy units that are detected.

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II. MODEL METHODOLOGY

A. BACKGROUND OPERATIONAL PREMISE

At the time of this writing, the Marine Corps plans to conduct a portion of the Urban Warrior AWE in Monterey, CA. As yet, the use of tactical unmanned systems is not explored in tactical urban situations on any large scale. The following statements describe a hypothetical political and military situation in order to illustrate the operational concepts that will drive the way a TUVL can be used.

1. Purpose for an Amphibious Operation

The interception of humanitarian relief supplies by several religiously based rival rebel factions in California has threatened the citizens of Monterey with starvation. A black market for the stolen supplies has developed, which has caused fighting between rival factions for control of the market. Massacres of ten to twenty men, women, and children are increasingly more common as the feuding intensifies. Each of the factions has acquired some unknown number of automatic weapons, indirect fire weapons, and air defense weapons.

Furthermore, the United States Embassy in Monterey is fired upon daily by sporatic unaimed small arms weapons. There have been reports of harassment, robbery, and assault of United States citizens in Monterey. The U.S. Ambassador in Monterey has requested evacuation of U.S. citizens as well as embassy personnel as soon as possible.

American foreign policy has placed emphasis on the situation in Monterey and plans were developed to aid the citizens of Monterey and to stop the rampant genocide that has been occurring. The National Command Authority has decided to land elements of a Marine Expeditionary Unit (MEU) at Monterey in order to evacuate American

citizens, secure the embassy, stabilize the region and restore unimpeded flow of humanitarian relief supplies to the region.

2. Scheme of Maneuver

Amphibious shipping remains far enough off-shore not to be detected by anyone in Monterey. One reinforced rifle company is inserted by MV-22 from over the horizon into the U.S. Embassy compound at the Defense Language Institute. The MV-22 is the tilt-rotor aircraft that will replace the aging CH-46 in the Corps' inventory early in the next century. The mission is to secure the embassy and begin the evacuation of American citizens. This is an example of Urban Penetration.

From over the horizon, a second reinforced rifle company will land by Advanced Amphibious Assault Vehicle (AAAV) on the beach adjacent to the Naval Postgraduate School (NPS). The company is accompanied by a platoon of Light Armored Reconnaissance (LAR) and two Light Armored Vehicle (LAV) 120mm mortar variants aboard Landing Craft Air Cushion (LCAC). The mission is to isolate and clear NPS, the principle military base of one of the rebel factions. This illustrates the employment of the Continuous Attack tactic.

Finally, the third reinforced company remains in reserve on the amphibious shipping off-shore. This unit will insert as necessary by MV-22 or AAAV in order to reinforce other units or to continue other phases.

B. TACTICAL UNMANNED VEHICLE LIGHT MISSION

Once isolation of NPS is achieved, two rifle platoons begin to clear the rebels from NPS. Each rifle platoon is organized into three squads for a total of six squads that clear NPS. Each squad leader has a number of TUVL systems available for his use. The

squad leader employs one system at a time, and deploys a new system after the current TUVL is killed. The TUVL mission is to provide the squad leader with a picture of the activities that are occurring in his zone before his troops arrive. In this scenario, the information gathered will consist of the location and disposition of enemy riflemen that can influence the squad's action within a zone.

C. JANUS SCENARIO DESCRIPTION

Janus is a high resolution combat model used by the Army and Marine Corps for analysis of ground combat operations. Janus is an interactive, multi-sided, closed, stochastic, ground combat simulation. [Ref. 7] Janus allows the user to make decisions while the simulation is running but does not allow one user to see all the forces of the opposing side. Once a scenario is developed to a point when no interaction with the game is necessary, Janus can run in AUTOJAN replay. Multiple runs of the same scenario can be replayed using a different random seed for each run. This enables the researcher to gather sufficient data to conduct statistical analysis.

The terrain used in the scenario is that of the Naval Postgraduate School. The buildings, roads, parking lots and vegetation are represented in the terrain file. The terrain is partitioned into six north-south zones, one for each squad. Each zone is about 100 meters wide, starts on Del Monte Boulevard and extends to California Route 1. The terrain is further partitioned into three phases by three east-west phase lines. The phase lines are no more than 200 meters apart in order to represent a 200 meter fiber optic cable that is used to transmit control signals and receive sensor output signals. The resulting 18 terrain blocks are characterized by varying terrain. Each block contains some combination of open terrain, parking lots, buildings and vegetation. The amount of each

terrain type in each block is difficult to quantify and is not balanced from block to block. However, this variability is representative of any urban environment where the TUVL is likely to be employed. Figure 1 shows the terrain. Zones are separated by vertical lines while phases are separated by horizontal lines.

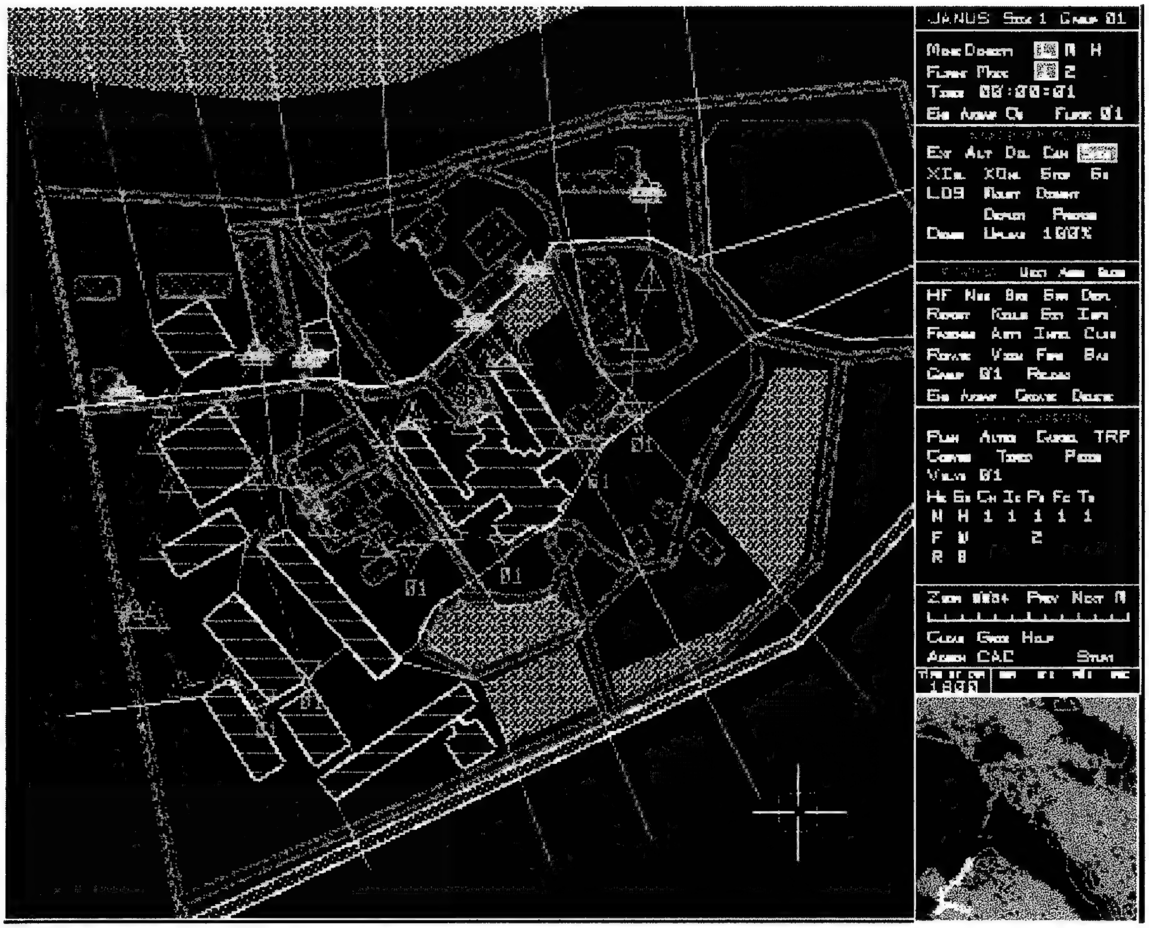

Figure 1. Terrain with TUVL Maneuver Commands.

Each block contains three rebel riflemen. Most of the riflemen are given movement commands that represent patrolling routes that the rebels use. Figure 2 depicts the location of the riflemen and the movement commands for only some of the riflemen.

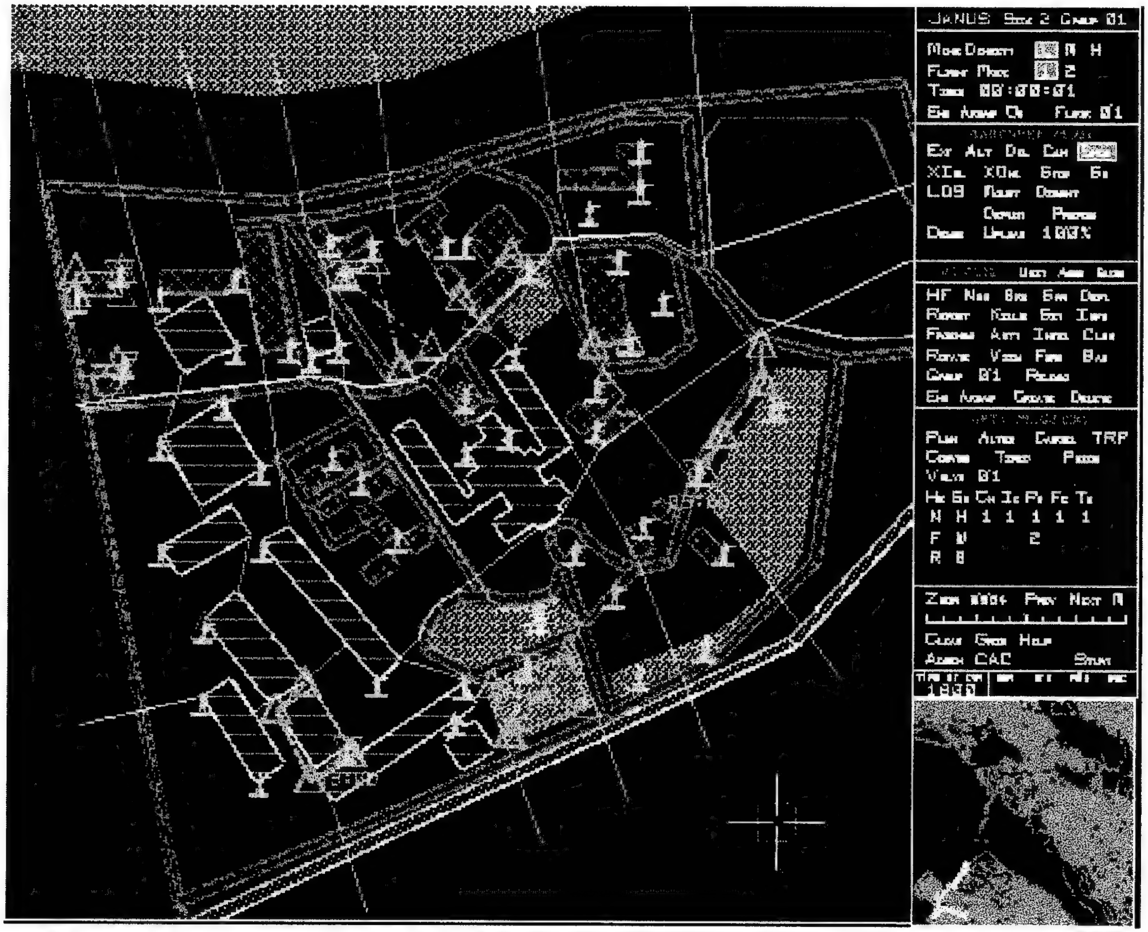

Figure 2. Riflemen Location and Maneuver Commands.

The TUVL is given movement commands that represent the route the squad leader would give to the TUVL to gain information on the rebels. Refer to Figure 1 to see movement commands for the TUVLs in the second phase. As the TUVL proceeds on its assigned route, Janus records detections made by both the TUVL and the riflemen. Janus also records the firing events that occur when a rifleman detects a TUVL and fires on it. If the rifleman hits the TUVL then the system is killed. Refer to Appendix A for a description of the detection and firing events and the way in which Janus displays the events.

D. JANUS DATABASE CONTRUCTION OF THE TUVL

There are many sizes and types of conceptual unmanned systems, from ones that are the size of a brick that only capture video, to an Amphibious Assault Vehicle that is used for mine-detection. In Janus, any of these systems can be modelled by changing the System, Weapons, and Sensors attributes in the Combat Systems database.

The TUVL as represented is 0.2 meters in length, 0.1 meters wide and 0.1 meters tall. The maximum road speed of the system is 5 kilometers per hour. The sensor height of the system is one meter. This height is limited by the database, which does not accept values less than one meter.

The TUVL is a wheeled system that weighs 30 pounds. Since the TUVL does not travel long distances, endurance of the TUVL is not a factor in this model. It is disregarded by giving the TUVL a very large fuel tank and a very low fuel consumption rate. The ability of the TUVL to carry equipment or passengers is also not a factor in this model. There are no weapons modelled on the TUVL; its only defense is its size and mobility. The Janus database characteristics of the TUVL are included in Appendix B. Modelling characteristics of the riflemen are not discussed but are also included in Appendix B.

The TUVL is modelled with a maximum visibility of one kilometer although in the area of NPS, the system will never experience that length of sight. The TUVL uses two optical (visible light) sensors. The primary sensor has a narrow field of view of 1.4 degrees and a wide field of view of 10.0 degrees. The purpose of using wide and narrow fields of view is to simulate searching for a target and fixation on a target respectively.

The secondary sensor has a field of view equal to 80 degrees. The probability of detection curves associated with these sensors are included in Appendix C.

Janus is limited in the way it can represent urban operations. Janus cannot model combat using interiors of buildings such as Joint Conflict and Tactical Simulation (JCATS). JCATS is a high-resolution combat model that models building interiors and varying building construction materials. Using Janus, the user cannot place forces inside of buildings. This capability of the model is crucial to more robust analysis of operations in urban settings. JCATS also models acoustic detection which is not available in Janus. The author tried using JCATS version 1.0, but experienced errors that prevented continued use. Other organizations are now experiencing good results using later versions. Various movement commands are not available in Janus when running in the AUTOJAN mode. If the above problems are corrected, then the modelling will more accurately represent operations using soldiers and marines.

The Janus scenario, framed by the underlying operational premise, is developed for the purpose of modeling the use of the TUVL in urban combat. The system characteristics give the reader an understanding of the size and capability of the TUVL. The following chapters detail the statistical analysis of the TUVL in urban operations.

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III. ANALYSIS METHODOLOGY

A. RUN MATRIX

The six TUVLs will execute the movement through their zones up to the first phase line in the first Janus scenario. Two more scenarios represent the TUVL maneuver executions up to the second and third phase lines. The data from these three scenarios is combined to create a data set for the entire zone. A fourth scenario is constructed that prevents the riflemen from shooting at the TUVL while the TUVL executes a continuous movement through all three phases without stopping at the phase lines. The terrain physically prevents some detections from occurring because of intervening structures, therefore the total number of riflemen on the battlefield does not represent the number of riflemen available for detection. The fourth scenario determines the number of detections that the TUVL has the opportunity to detect if the TUVL is immortal or not detected by the riflemen. Each scenario is run ten times in the AUTOJAN mode based on a randomly selected seed. Each run from scenarios 1-3 produce a detection report and direct fire report. Runs from scenario four only produce a detection report. A summary of the data is contained in Appendix D.

B. MEASURE OF EFFECTIVENESS DESCRIPTION

This thesis emphasizes the survivability and detection capability of the TUVL. The analysis is concerned with the differences in TUVL performance when movement status of the riflemen changes or when the terrain changes.

1. MOE 1

The first measure of effectiveness that is explored is the average detection range for a TUVL that is moving and exposed, detecting a riflemen that is either moving and

exposed (ME) or stationary and in defilade (SD). This measure of effectiveness is important in developing tactics for employing TUVL systems in urban environments.

2. MOE 2

The next measure of effectiveness is the average detection range of the TUVL in each zone detecting riflemen regardless of movement status of the riflemen. This analysis will examine the performance of the TUVL over varying terrain. This measure of effectiveness is also important in developing employment strategies for TUVL systems.

3. MOE 3

The third measure of effectiveness is the proportion of riflemen detected by the TUVLs. This experiment will utilize the number of detections in each zone from the fourth scenario to determine the number of riflemen that are available for detection by the TUVLs in the other three scenarios. This measure is useful in estimating the size of the opposing force and in a cost-benefit analysis.

4. MOE 4

The fourth and final measure of effectiveness is the proportion of total shots taken by the riflemen that hit the TUVL. The Probability of Hit (Ph) and Probability of Kill (Pk) tables in the Janus database are constructed in order to guarantee that if the TUVL is hit, then the TUVL is killed. At any range, given that the TUVL is hit, then the probability that the TUVL dies is equal to one. The assumption is that the TUVL is a machine dense with electronics and mechanisms that will not survive the impact of a bullet. The Ph plots are included in Appendix E. This measure will demonstrate

whether physical dimension of the vehicle is important in an urban setting and whether it should be considered in the development of TUVL systems.

C. DATA ANALYSIS METHODS

1. Testing for normality of the distributions

The Kolmogorov-Smirnov (KS) test statistic is based on the maximum magnitude of difference between the sample cumulative distribution function (CDF) and the hypothesized CDF. [Ref. 8, p.424] This test is performed using the estimated sample mean and sample standard deviation. The test provides a p-value that is evaluated for significance. The normality assumption is crucial to the inferences that will follow.

When the null hypothesis assumes that a sample comes from a normal distribution, and the hypothesis is rejected in a goodness-of-fit test, it is often possible to make transformations of the data that may make the null hypothesis acceptable. A list of possible transformations is available in Reference 9, p. 20-5. Now that the normality assumption of each sample is viable, inferences can be made concerning the distribution parameters.

2. Testing for equality of the variances

The F test is used to compare the variances from two samples with unknown parameters. [Ref. 10:p. 372] The assumptions for the F test are that the two samples come from normal distributions and are independent. The sample means do not have to be equal. The null and alternative hypotheses are:

$$H_o: \sigma_x^2 = \sigma_y^2 \qquad (1)$$

$$H_1: \sigma_x^2 \neq \sigma_y^2$$

The F test statistic is formed by the ratio of the two sample variances. For a given level of significance (α), the test statistic (*TS*) is compared to a critical value of the F distribution.

$$TS = \frac{s_y^2}{s_x^2} \tag{2}$$

When n is the size of a sample drawn from the distribution of X and m is the size of a sample drawn from the distribution of Y, the decision rule rejects the null hypothesis if:

$$TS \text{ is either } \begin{cases} \leq F_{\frac{\alpha}{2}}, m-1, n-1 \\ or \\ \geq F_{1-\frac{\alpha}{2}}, m-1, n-1 \end{cases} \tag{3}$$

where $F_{\frac{\alpha}{2},m-1,n-1}$ and $F_{1-\frac{\alpha}{2},m-1,n-1}$ are the $\frac{\alpha}{2}$ and $1-\frac{\alpha}{2}$ quantiles, respectively, of the F distribution with *m-1* and *n-1* degrees of freedom.

3. Testing for equality of the means

Drawing inferences concerning sample means is much more difficult in cases where the null hypothesis about the equality of variances is rejected. This case is known as the Behrens-Fisher problem. [Ref. 10:p. 362] An adjusted degree of freedom value is computed in order to deal with the Behrens-Fisher problem. Welch's solution for the estimated degree of freedom (ν) is: [Ref.11]

$$\nu = \frac{\left({s_x^2}/{m} + {s_y^2}/{n} \right)^2}{\left[{\left(s_x^2/m\right)^2}/{(m-1)} \right] + \left[{\left(s_y^2/n\right)^2}/{(n-1)} \right]} \tag{4}$$

The adjusted degree of freedom (ν) is used in the standard T test in place of the degree of freedom (*m+n-2*). The T test uses an estimate of the pooled sample variance given by the formula:

$$S_p^2 = \frac{(m-1)s_x^2 + (n-1)s_y^2}{m+n-2} \tag{5}$$

The assumptions for the T test are that each of the two samples come from a normal distribution, that the two samples have equal variances, and that the two samples are independent of each other. [Ref. 10:p. 362]

The null and alternative hypotheses are:

$$H_o : \mu_x = \mu_y$$

$$H_1 : \mu_x \neq \mu_y$$

The test statistic for the T test is:

$$TS = \frac{\overline{x} - \overline{y}}{S_p\sqrt{\frac{1}{m} + \frac{1}{n}}}$$

When *n* is the size of a sample from the distribution of *X* and *m* is the size of a sample from the distribution of *Y*, the decision rule rejects the null hypothesis if:

$$TS \text{ is either } \begin{cases} \leq -t_{\frac{\alpha}{2},m+n-2} \\ or \\ \geq +t_{\frac{\alpha}{2},m+n-2} \end{cases} \tag{6}$$

where $\pm t_{\frac{\alpha}{2},m+n-2}$ are the $\frac{\alpha}{2}$ and $1-\frac{\alpha}{2}$ quantiles, respectively, of the t-distribution with *m+n-2* degrees of freedom.

If the null hypothesis from Equation (1) cannot be rejected then criterion (6) is used for inferences about the equality of the sample means. However, if the null hypothesis is rejected by expression (3), then the degree of freedom (ν) that is given by Equation (4) is used in the decision rule. Reject the null hypothesis if:

$$TS \text{ is either } \begin{cases} \leq -t_{\frac{\alpha}{2},\nu} \\ or \\ \geq +t_{\frac{\alpha}{2},\nu} \end{cases}$$

The three tests that have been discussed will be used to analyze each measure of effectiveness that concerns detection ranges. However, these methods have disadvantages when multiple paired comparisons are conducted. Let α' denote the "overall" Type I error for an experiment, or the probability of rejecting at least one true H_0. So, since this experiment involves 15 paired comparisons at $\alpha = 0.05$ level of significance, the probability of rejecting at least one true null hypothesis may increase as high as 0.54. [Ref. 10:p. 523] Simultaneous tests may be preferred that do not change the behavior of the level of significance.

Analysis of variance (ANOVA) procedures are used very often for simultaneous F tests. In this experiment the ANOVA problem is a two-way, cross-classified ANOVA. This type of ANOVA tests the null hypothesis that the different levels of a factor have no effect on the true average of the response variable. A null hypothesis such as this is made for each factor in the analysis. [Ref. 12:p. 424] ANOVA only points out that levels of a factor have a significant impact on the value of the response, but this method does not show which levels make the difference. In order to show where the differences exist, the analyst uses methods that determine simultaneous confidence intervals for the paired

differences in means without effecting the interpretation of the level of significance. The Tukey method is used for this purpose. [Ref. 12:p. 402]

Tukey's procedure utilizes the Studentized range distribution. This distribution is parameterized by the level of significance, the degrees of freedom in the numerator and in the denominator. If I and J denote the pair of means that are to be compared, then the quantile $Q_{\alpha,I,I(J-1)}$ can be used to obtain simultaneous confidence intervals for all pairwise differences of two means. [Ref. 12:p. 402]

There are non-parametric ANOVA methods that are useful as well. The Kruskal-Wallis test is a one-way non-parametric ANOVA. This method tests the null hypothesis that the median values of all samples are equal against the alternative that any two medians are not equal. This method involves ordering the entire data set of all samples and computing the rank sum for each sample. The Kruskal-Wallis test statistic is compared to a chi-square quantile. [Ref. 10:p. 567] If the test statistic is larger than the critical value, then it is appropriate to reject the null hypothesis in favor of the alternative.

The Friedman test is a two-way non-parametric ANOVA for blocked data where each cell contains one observation. [Ref. 10:p. 571] This procedure is based on the rank of the data from a sample within each block. The test statistic for this method takes a similar form to the Kruskal-Wallis test as well as drawing the critical value from the chi-square distribution. Once again, one must reject the null hypothesis when the test statistic is greater than the critical value.

4. Testing for equality of proportions for binomial data

The probability of success in two samples of Bernoulli trials is examined in order to make inferences concerning population proportions. [Ref.11:p. 378] The data

available are m Bernoulli trials related to treatment X and n Bernoulli trials related to another treatment Y, independent of X. There are x successes in m trials from X and y successes in n trials from Y. If p_x and p_y are the true probabilities of success for treatments X and Y respectively, and we wish to test the equality of p_x and p_y, then the null and alternative hypotheses are:

$$H_o: p_x = p_y$$
$$H_1: p_x \neq p_y$$

Larsen and Marx [Ref.10:p. 380] construct the test statistic (*TS*) in the following manner by considering the central limit theorem results:

$$TS = \frac{\frac{x}{m} - \frac{y}{n}}{\sqrt{\frac{\left(\frac{x+y}{m+n}\right)\left(1 - \frac{x+y}{m+n}\right)(m+n)}{mn}}} \tag{7}$$

At a specified level of significance (α), the *TS* is compared to a critical value from the standard normal distribution according to the following decision rule:

$$\text{Reject the null hypothesis if } TS \text{ is either } \begin{cases} \leq -z_{\frac{\alpha}{2}} \\ or \\ \geq +z_{\frac{\alpha}{2}} \end{cases} \tag{8}$$

while the boundaries are quantiles of the standard normal distribution.

The method just described tests the equality of population proportions against the alternative that the proportions are different but makes no statement about which proportion is truly greater. [Ref. 11:p. 8-18] The test that follows determines whether there is enough evidence to suggest that one population proportion is greater than

another. Let $p_A = r_A/n_A$ and $p_B = r_B/n_B$ where r_A and r_B are the number of successes in n_A and n_B trials respectively. Also, let $s = s_A + s_B$, the total number of failures from both samples. Then the chi-square test statistic is:

$$TS = \frac{n\left(\left|r_A * s_B - r_B * s_A\right| - \frac{n}{2}\right)}{n_A * r * n_B * s} \tag{9}$$

where $r = r_A + r_B$ and $n = n_A + n_B$. The quantile $\chi^2_{1-2\alpha}$ is the critical value that is compared to the test statistic when α is the level of significance. If p_A is greater than p_B, and *TS* is greater than the critical value, then the population proportion of population A is greater than the population proportion of population B.

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IV. RESULTS

A. KOLMOGOROV-SMIRNOV TEST

As explained in the third chapter, the KS test compares the maximum magnitude of difference in distribution function values between the empirical distribution under investigation and a specified distribution. In this case, that specified distribution is the normal distribution with parameters equal to the sample mean and sample variance. The samples MEonME and MEonSD contain the detection ranges for a ME TUVL detecting a ME Riflemen and a ME TUVL detecting a SD Riflemen, respectively. The samples Zone1 through Zone 6 contain the detection ranges at which each TUVL detects riflemen in the TUVL's zone regardless of TUVL or riflemen movement or exposure status. Summary statistics for the samples this thesis examines for MOE 1 and MOE 2 are contained in the following table.

	Mean	Sample Size	Standard Deviation	Variance	KS p-value	Significant
MEonME	0.137	78	0.1133	0.0128	0.0348	yes
MEonSD	0.082	422	0.0556	0.0031	0.0001	yes
Zone1	0.101	71	0.0726	0.0053	0.1413	no
Zone2	0.089	118	0.0543	0.0029	0.1978	no
Zone3	0.087	80	0.0659	0.0043	0.0012	yes
Zone4	0.094	70	0.0650	0.0042	0.0016	yes
Zone5	0.085	87	0.0761	0.0058	0.0129	yes
Zone6	0.089	81	0.0894	0.0080	0.0023	yes

Table 1. Summary statistics and KS test results

This table shows the significant difference between most of these samples and the normal distribution with the same parameters. Therefore, data transformations are used in an effort to classify the transformed data as data drawn from a normal distribution. A power transformation is used on the MEonME and MEonSD data. For these cases the

data was raised to the 0.3 power. The detection ranges in the individual zones needed more sophisticated transformations. [Ref. 9:p. 20-5]

The transformation used is:

$$\log_e \frac{X}{1-X}$$

which rescales the range interval and flattens the tails of the distribution.

The table that follows contains the summary statistics, p-values, and significance of the transformed variables.

	Mean	Sample Size	Standard Deviation	Variance	KS p-value	Significant
ptMEonME	0.517	78	0.1259	0.0158	0.8046	no
ptMEonSD	0.448	422	0.0996	0.0099	0.3485	no
tZone1	-2.47	71	0.9513	0.9049	0.2492	no
tZone2	-2.51	118	0.7058	0.4981	0.1338	no
tZone3	-2.62	80	0.8524	0.7265	0.4955	no
tZone4	-2.55	70	0.9415	0.8865	0.5083	no
tZone5	-2.83	87	1.1498	1.3221	0.1389	no
tZone6	-2.59	81	0.7934	0.6294	0.7810	no

Table 2. Summary statistics of the transformed data and KS test results

The transformed data is assumed to be from normal distributions since none of the KS test results are significant. With this assumption, we are ready to examine the equality of variance between data sets.

B. TWO-SAMPLE TEST USING THE F-STATISTIC

The test statistic used in the F test is computed using Equation (2). The F test is demonstrated for MOE 1, average detection range of ME TUVL detecting either ME Riflemen or SD Riflemen, while the results for MOE 2, average detection range in each zone, are contained in Appendix F.

$$TS = \frac{0.0158}{0.0099} = 1.5960$$

The critical value is computed for the quantile from the F distribution:

$$F_{.975,77,421} = 1.3837$$

Since *TS* is greater than $F_{.975,77,421}$, there is a significant difference in the sample variances of these two samples. The two sample T test that is used to make inferences about equality of the means assumes that the sample variances are equal. However, in this case they are not equal. This results in an example of the Behrens-Fisher problem.

C. TWO-SAMPLE TEST USING THE T-STATISTIC

There are many solutions that have been proposed to deal with the Behrens-Fisher problem. The use of Welch's solution, Equation (4), is computed for MOE 1: [Ref. 11, p.358]

$$\nu = \frac{\left(0.0158/78 + 0.0099/422\right)^2}{\left[(0.0158/78)^2 / (77)\right] + \left[(0.0099/422)^2 / (421)\right]} = 95.63$$

Very little accuracy is lost by simply rounding ν to the nearest integer. Now that the adjusted degree of freedom is known, construction of the test statistic continues. The pooled estimate of the variance is needed to compute the test statistic. Recall Equation (5).

$$S_p^2 = \frac{(77)*0.0158 + (421)*0.0099}{78 + 422 - 2} = 0.0108$$

Now with all the pieces, the test statistic (*TS*) is assembled:

$$TS = \frac{0.5171 - 0.4479}{0.1039\sqrt{\frac{1}{78} + \frac{1}{422}}} = 5.403$$

TS is compared to $t_{0.025,96}$. *TS* is greater than the critical value, therefore when $\alpha = 0.05$, there is a significant difference between the mean range of a ME TUVL detecting a ME Riflemen and a ME TUVL detecting a SD Riflemen.

The procedure described above is the same for MOE 2, although only two of fifteen paired comparisons fall into the realm of the Behrens-Fisher problem. The remaining thirteen comparisons utilize the standard T test with degree of freedom *m+n-2*. The results of both types of computations are contained in Appendix F. The analysis reveals that there is a difference in average detection range between the TUVL in Zone 1 and the TUVL in Zone 5 and also between the TUVL in Zone 2 and the TUVL in Zone 5. An analysis of the terrain, (see Appendix A), shows that there are more obstacles in Zone 5 than Zone 1 or Zone 2 that hinder the LOS of the TUVL.

D. MULTIPLE COMPARISONS

For the reasons mentioned in the previous chapter, the results of several individual paired comparisons should be further examined. A two-way Analysis Of Variance (ANOVA) using the transformed response data with status and zones as factors is constructed. The levels of status are ME and SD while the levels of zones are the six zones used by the TUVLs. In Table 3, the results of this ANOVA show that zone and the interaction of zone and status are not significant contributors to a difference in average detection range of a TUVL detecting riflemen. However, status contributes to the difference in average range. This result further solidifies the result of the paired T test conducted for average detection range of a TUVL detecting either a ME Riflemen or a SD Riflemen.

SOURCE	DF	SS	MS	F-VALUE	Pr(F)
ZONE	5	6.726	1.345	1.734	0.125
STATUS	1	17.226	17.226	22.201	0.000
INTERACTION	5	2.934	0.587	0.756	0.582
ERROR	495	384.080	0.776		

Table 3. ANOVA results for MOE 2

The results of non-parametric ANOVA methods also support those of the parametric ANOVA. For this use of the Friedman test, the mean of the data in the status/zone cell is used as the single observation. Since the test uses a blocking variable, the test is conducted twice. The first test considers status as the block. In this case, the Friedman test fails to reject the null hypothesis that the within status mean detection ranges are equal with a p-value equal to 0.5494. Additionally, when zone is the blocking variable, the test accepts the null hypothesis that the within zone mean detection ranges are equal with a p-value of 0.0143.

One Kruskal-Wallis test is conducted twice, once for zone and once for status. With a p-value of 0.089 the test does not reject the null hypothesis that the effect of zone is zero. However, the test concludes that the effect due to status is not zero with a p-value that is essentially zero. The Friedman test refutes the ANOVA results while the Kruskal-Wallis test supports the full model ANOVA results.

E. POPULATION PROPORTIONS

1. MOE 3

This method of testing the equality of proportions is used to examine both MOE 3, proportion of riflemen detected in each zone, and MOE 4, proportion of shots that kill a TUVL.

Using Equation (7), the test statistic is computed comparing the detection performance of the TUVL from Zone 1 with that of the TUVL from Zone 5:

$$TS = \frac{\frac{71}{187} - \frac{87}{277}}{\sqrt{\frac{\left(\frac{71+87}{187+270}\right)\left(1-\frac{71+87}{187+277}\right)(187+277)}{187*277}}} = 1.463$$

The results for the other zone to zone comparisons are included in Appendix F.

When $\alpha = 0.05$ the critical value is computed using Equation (8). For this level of significance, the critical value is $z_{.975} = 1.96$. The critical value is ± 1.960 for each of these comparisons. The test statistic is less than the critical value, hence, there is not enough evidence to reject the null hypothesis that the sample proportions are equal. Therefore, there is no difference between the proportion of riflemen detected by the TUVL in Zone 1 and the proportion detected by the TUVL in Zone 5.

However, the previous method may be flawed by a familywise error rate problem. Therefore, the author constructs simultaneous confidence intervals, using the Tukey method, where the stated level of significance covers the entire experiment instead of just one paired comparison. The counts and proportions used in this method are contained in Table 4, while the bounds of the confidence intervals and results of the test are located in Appendix F.

ZONE	HIT	NOT HIT	TOTAL	P
1	71	116	187	0.380
2	118	134	252	0.468
3	80	228	308	0.260
4	70	231	301	0.233
5	87	190	277	0.314
6	81	209	290	0.279
TOTAL	507	1108	1615	

Table 4. Counts and proportions for MOE 3

The results of the two tests, pairwise comparisons and simultaneous comparisons, are very similar. Out of the fifteen pairwise comparisons, eight of the comparisons resulted in a difference, while seven of the comparisoons show a significant difference using the simultaneous confidence interval method.

2. MOE 4

The following analysis uses the data in Table 5.

ASPECT	HIT	NOT HIT	TOTAL	P
FRONT	53	60	113	0.469
HULL	123	193	316	0.389
TOTAL	176	253	429	

Table 5. Counts and proportions for MOE 4

This table contains the counts for number of hits, number of misses, total number of shots taken by the riflemen, and population proportions. The data from this table is used in a two-sided test for equal population proportions as well as a one-sided test for equality of proportions.

This two-sided test statistic for MOE 4 is computed as it was for MOE 3:

$$TS = \frac{\frac{53}{113} - \frac{123}{316}}{\sqrt{\frac{\left(\frac{53+123}{113+316}\right)\left(1-\frac{53+123}{113+316}\right)(113+316)}{113*316}}} = 1.480$$

The level of significance and critical value are the same as those for analysis of MOE 3. Therefore, there is not enough evidence to reject the null hypothesis that the success of direct fire events is the same for frontal shots as for flanking shots. This test is a two-sided test. Next, a one-sided test is conducted. It may be possible to discover a

difference in proportions by using a one-sided test that was not evident using a two-sided test.

The one-sided test statistic is computed using Equation (8):

$$TS = \frac{429 * \left(|53 * 193 - 123 * 60| - \frac{429}{2} \right)^2}{113 * 176 * 316 * 253} = 1.873$$

The critical value for this test is $\chi^2_{.9,1} = 2.71$. Since the test statistic is less than the critical value, there is not enough evidence to reject the null hypothesis that the population proportions are the same.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The analysis reveals that there is a significant difference between the mean range of detection of a ME TUVL detecting a ME Rifleman and a ME TUVL detecting a SD Rifleman. A ME TUVL detects a ME Rifleman at a longer range than it detects a SD Rifleman. This makes perfect sense. A target that is in defilade does not present a full size target to the detecting sensor. Additionally, a target that is stationary is usually more difficult to detect than a moving target.

Each of the six TUVLs is compared with every other TUVL to uncover differences or similarities in average detection range from zone to zone. The analysis reveals that there is a difference in average detection range between the TUVL in Zone 1 and the TUVL in Zone 5 and also between the TUVL in Zone 2 and the TUVL in Zone 5. The other thirteen comparisons did not reveal significant differences in average detection range. The terrain in Zone 5 is very narrow and the view is very obstructed. There is more opportunity for the TUVLs in Zone 1 and Zone 2 to see farther than the TUVL in Zone 5.

However, the conclusions of the multiple comparisons are different. The full model two-way ANOVA, the Kruskal-Wallis test, and the Friedman tests agree with each other but disagree with the results of the individual pairwise comparisons. Using the multiple comparison methods, there is no effect due to terrain. However, there is a terrain effect using the individual paired comparisons. Since intuition leads one to say that terrain should be important to the detection capability of the TUVL, more analysis is

necessary to determine the effect of terrain on the capability of the TUVL to detect targets.

Additional comparisons are conducted using the proportion of riflemen detected by each TUVL. Examination of MOE 3 reveals that terrain is an important factor in the detection capability of a TUVL. Using individual paired comparison methods, eight of the fifteen paired comparisons are statistically significant with respect to the proportion of riflemen detected, while seven pairs offer significant differences using simultaneous paired comparisons.

The analysis of MOE 4 determined that there is no difference between the proportion of shots that hit a TUVL from the front or rear and the proportion of shots that hit a TUVL from the side. Therefore, the aspect of the target, or the surface area of the target presented to the Riflemen, is not a factor in determining the probability of a TUVL being hit. Most likely, this is due to the relatively small size of the TUVL at the distances at which the riflemen engage the TUVL. As a result of constructing a simulation using the TUVL in a tactical scenario, several insights concerning possible equipment modifications and TTPs are evident to the author.

B. TACTICAL AND ACQUISITION INSIGHTS

The following tactical and acquisition insights are derived from the author's experience of writing this thesis and experience in Marine Corps operational units. First, an operational concept is described. Then, the tactical and acquisition insights are described that apply to the stated concept.

1. Acoustic Detection

The capability of a TUVL to audibly detect should be helpful in the effective tactical use of the system in most missions and situations. Acoustic sensors can be used as a direction finder to important activities. Specifically, the TUVL with a microphone can pinpoint the location from which sniper fire is coming. The TUVL could give a commander information about the attitude of a crowd by listening in on the rhetoric of a speaker. The types of vehicles an enemy uses and whether or not they are running can be determined without seeing the vehicles by listening to the engine noise. The list of examples is endless. From an acquisition standpoint, an acoustic capability is easily achieved. Microphones are cheap, small, and light.

2. Laser pointing

Once detection of the enemy has occurred, locating the enemy on a map is the next step toward engagement of that target. Usually, the picture that the TUVL sees is transmitted to the controller of the TUVL. The controller then must plot the position on a map. Some systems may produce a grid location for where the TUVL is looking automatically. In the urban setting, accuracy in target location is much more important than in open terrain. The safety margin for errors is much smaller. A laser pointing device can be used to achieve that level of accuracy. The laser should be infrared so it is only visible to entities with night vision capability. The TUVL can put the laser dot on a window of a building or specific vehicle. A machine gunner or helicopter gunner using night vision goggles then knows the exact target. The technology is available to employ this capability on the TUVL. Small lasers are readily available from hardware or office supply stores. Again, these devices are inexpensive, light, and small.

3. Infrared chemical lights

TUVL systems can be used as a route reconnaissance element. It is helpful if the TUVL can mark a route through difficult terrain. Visible and infrared chemical lights are used often for this application. However, the lights must be placed by personnel. A chemical light dispenser mounted on a TUVL can be used instead. The use of the TUVL prevents a loss in manpower and prevents risk to the personnel required to manually emplace the lights. The dispenser would not be expensive and the size is minimal. Infrared chemical lights are small, 1-1/2 inches by 1/8 inches.

4. Controlling the TUVL

Currently there are two ways to tactically control the TUVL. One way is through the use of radios. The other method is through the use of a fiber optic cable. Both methods have advantages and disadvantages. The use of radio frequency (RF) control is vulnerable to jamming and radio direction finding by the enemy, although radio signals can be secured using encryption techniques. However, in an urban setting building structures inhibit the use of radios. Radios are also heavy for their size and require power sources that are also heavy.

Fiber optic cable is not effected by building structures. Fiber optic cable does not use any portion of the frequency bandwidth that will be in short supply as more and more systems strive to communicate with each other. However, fiber optics are fragile and easily broken. The wire is not retrievable or reusable. If the cable is broken, control is lost and the vehicle is immovable. The wire can be followed to its source (controller) or terminal (TUVL). This presents a danger to the systems at both ends of the wire.

5. Tactics, Techniques, and Procedures

While writing this thesis, the author discovered that the positive and negative attributes associated with employment of the TUVL point to a few conclusions concerning Tactics, Techniques, and Procedures and the acquisition process. The TUVL used in an urban environment does not enjoy a long life. TUVL systems will suffer casualties just as an infantryman would given the same mission. Therefore, the TUVL should be acquired under the assumption that the system is expendible. The limits of the two controlling methods place a range limitation on the TUVL. This system is not a long or even medium range system. The TUVL should be employed to scout around corners and down alleys or hallways, not for reconnaissance of the next five city blocks.

Under this tactical assumption, acquisition assumptions surface. If the TUVL is employed as an expendible system, then it should be inexpensive. Additionally, since many systems will be needed, and those systems may need to be transported by infantrymen, the TUVL needs to have weight limitations. The sensors that are attached to the TUVL should be inexpensive. There is no sense putting a third generation infrared sensor on the TUVL.

C. RECOMMENDATIONS

There are many opportunities for future study using a similar model. One recommendation is to model the TUVL as if it was placed in an area covertly and remained in position. This allows the TUVL to simply look, listen, and communicate its findings. The implemention of acoustic sensing and construction of building interiors, doors and windows are additions to the model that expand analysis opportunities and more closely represent an urban environment. JCATS, mentioned earlier, is a tool that

can be used. Finally, it is beneficial to model the TUVL in a force on force scenario in order to gain insight into the effects on attrition and the changes the TUVL makes in the commanders decision cycle. Although this type of experiment takes more time to model, more time to run and requires increased manpower, there is value to the analysis.

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APPENDIX A. JANUS GRAPHICAL DISPLAY

This appendix shows the Janus screen for the TUVL side of the simulation. The TUVLs are blue while the riflemen are red. On the display of the riflemen side, the colors are reversed. This display shows that one TUVL was suppressed (S) and subsequently suffered a catastrophic kill (C). The riflemen that are visible on this screen are only those that are identified by the TUVL systems.

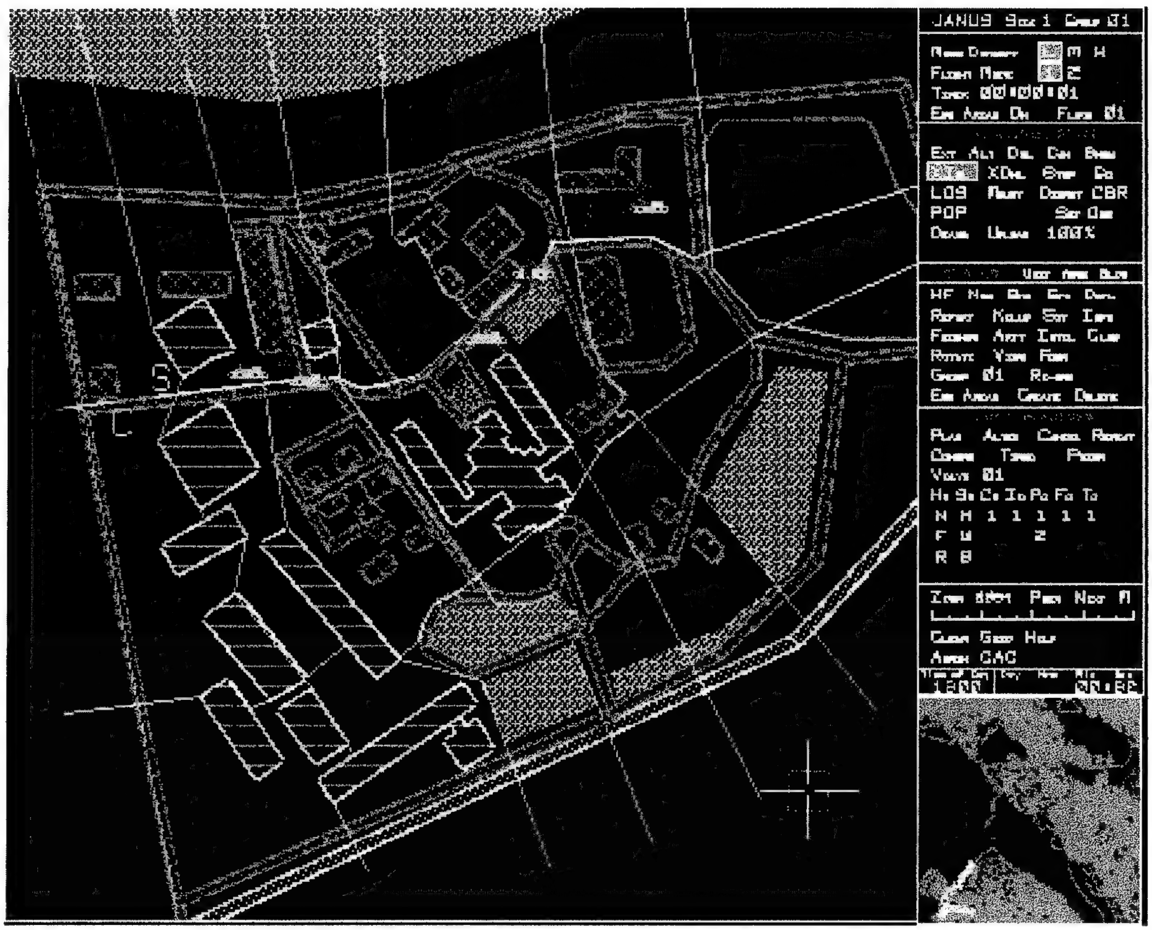

Figure 3. The Janus screen for the TUVL side.

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APPENDIX B. SYSTEM DATABASE CHARACTERISTICS

Sys Name	Road Speed (Km/hr)	Sens Hgt (m)	Max Vis (Km)	Wpn Rng (Km)	Elem Spa (m)	Gph Sym	Det Sym	Lsr Dsg	Eng Typ	Fir Typ
Riflemen	5	1	0.2	0.5	40	69	69		6	1
TUVL	5	1	1	0		50	50			

Sys Name	Fly Typ	Mov Typ	Rad Typ	Swm Typ	Smk Typ	Min Typ	Log Typ	Srv Typ	ChemX Factr	Crw Siz
Riflemen		3		1					1	1
TUVL		2							1	1

Sys	Detection Dimension (m)			Sensor			Thermal	Contrast	Optical	Popup
Name	Length	Width	Height	1	2	3	Exposed	Defilade	Contrast	Capable
Riflemen	0.5	0.5	1	1	2	1	0.35	5	5	1
TUVL	0.2	0.1	0.1	5	4	4	0.35	0	0	1

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APPENDIX C. SENSOR PLOTS

These plots show the probability of detection at a given range for each sensor on a rifleman detecting a TUVL. The rifleman has two sensors, each with a pair of detection curves. One line shows the probability of acquisition while the system is ME while the other shows the probability when the system is SD.

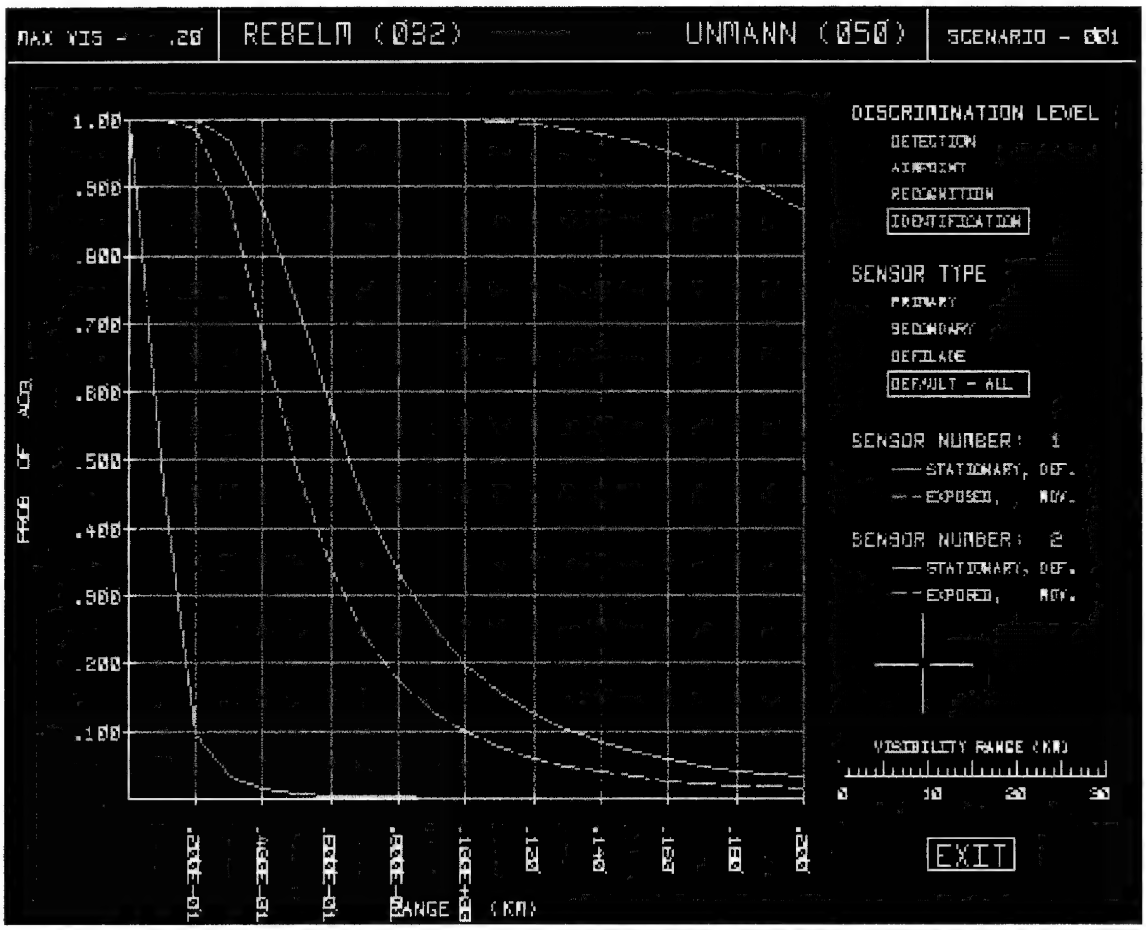

Figure 4. Riflemen Sensor Plot

The user can select the discrimination level and the sensor type. At a given range, the probability of identification is less than the probability of recognition, which is less than the probability of detection. Detection occurs when the sensor sees a target.

Recognition occurs when the target is classified as a certain class of targets, such as a tank. Identification occurs when the target is classified as a certain system; a T-72 tank for example. Simply, as a target approaches the sensor, detection occurs first, then recognition and finally identification. More information about these plots is available in Reference 7.

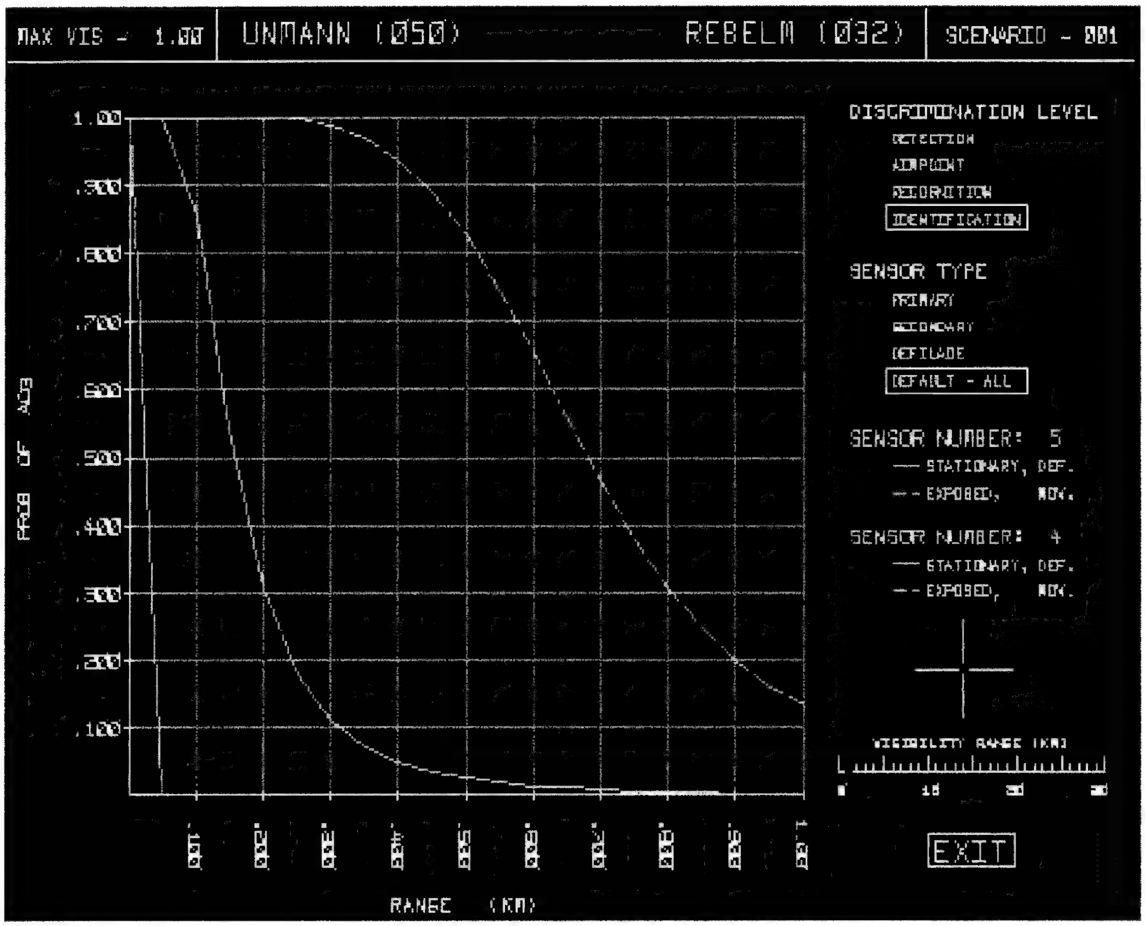

Figure 5. TUVL Sensor Plot

APPENDIX D. SAMPLE OF THE DATA

A. SAMPLE DIRECT FIRE REPORT

			DIRECT	FIRE	REPORT					
GAME			FIRER			TARGET				
TIME	UNIT	SIDE	NAME	UNIT	SIDE	NAME	SPEED	STAT	SSKP	RANGE
00:00:02:10	2	2	REBELM	3	1	UNMANN	2.5	SMEF	0.31	0.194
00:00:02:12	2	2	REBELM	3	1	UNMANN	2.5	SMEF	0.31	0.192
00:00:02:15	2	2	REBELM	3	1	UNMANN	2.5	SMEF	0.31	0.192
00:00:02:18	2	2	REBELM	3	1	UNMANN	2.5	SMEF	0.31	0.192
00:00:02:56	53	2	REBELM	6	1	UNMANN	2.5	SMEF	0.52	0.055
00:00:02:59	53	2	REBELM	6	1	UNMANN	2.5	SMEF	0.52	0.055
00:00:03:02	53	2	REBELM	6	1	UNMANN	2.5	SMEF	0.52	0.052
00:00:03:04	53	2	REBELM	6	1	UNMANN	2.5	SMEF	0.52	0.052
00:00:03:07	53	2	REBELM	6	1	UNMANN	2.5	SMEH	0.53	0.045
00:00:03:11	28	2	REBELM	5	1	UNMANN	2.5	SMEF	0.32	0.184
00:00:03:14	28	2	REBELM	5	1	UNMANN	2.5	SMEF	0.32	0.184
00:00:03:14	38	2	REBELM	5	1	UNMANN	2.5	SMEF	0.48	0.08
00:00:03:41	28	2	REBELM	4	1	UNMANN	2.5	SMEF	0.59	0.009
00:00:03:44	28	2	REBELM	4	1	UNMANN	2.5	SMEF	0.59	0.009
00:00:03:46	1	2	REBELM	1	1	UNMANN	2.5	SMEF	0.49	0.075
00:00:03:48	1	2	REBELM	1	1	UNMANN	2.5	SMEF	0.49	0.075
00:00:06:34	3	2	REBELM	2	1	UNMANN	2.5	SMEF	0.42	0.118
00:00:06:46	3	2	REBELM	2	1	UNMANN	2.5	SMEF	0.42	0.118
00:00:06:48	3	2	REBELM	2	1	UNMANN	2.5	SMEF	0.42	0.118
00:00:06:51	3	2	REBELM	2	1	UNMANN	2.5	SMEF	0.41	0.124
00:00:06:54	3	2	REBELM	2	1	UNMANN	2.5	SMEF	0.41	0.124
00:00:00:53	53	2	REBELM	5	1	UNMANN	2.5	SMEF	0.32	0.19
00:00:00:56	53	2	REBELM	5	1	UNMANN	2.5	SMEF	0.32	0.19
00:00:00:59	53	2	REBELM	5	1	UNMANN	2.5	SMEF	0.32	0.19
00:00:01:01	53	2	REBELM	5	1	UNMANN	2.5	SMEF	0.32	0.185
00:00:01:04	53	2	REBELM	5	1	UNMANN	2.5	SMEF	0.32	0.185
00:00:02:14	29	2	REBELM	4	1	UNMANN	2.5	SMEF	0.48	0.08
00:00:02:17	29	2	REBELM	4	1	UNMANN	2.5	SMEF	0.48	0.08
00:00:02:20	29	2	REBELM	4	1	UNMANN	2.5	SMEF	0.48	0.08
00:00:02:22	29	2	REBELM	4	1	UNMANN	2.5	SMEF	0.49	0.074
00:00:02:34	19	2	REBELM	3	1	UNMANN	4.5	SMEH	0.36	0.158
00:00:03:07	11	2	REBELM	2	1	UNMANN	2.5	SMEH	0.46	0.093
00:00:03:35	53	2	REBELM	6	1	UNMANN	2.5	SMEH	0.55	0.032
00:00:03:38	53	2	REBELM	6	1	UNMANN	2.5	SMEH	0.56	0.025
00:00:03:40	1	2	REBELM	1	1	UNMANN	2.5	SMEF	0.48	0.081
00:00:03:42	1	2	REBELM	1	1	UNMANN	2.5	SMEF	0.49	0.075
00:00:03:45	1	2	REBELM	1	1	UNMANN	2.5	SMEF	0.49	0.075
00:00:03:48	1	2	REBELM	1	1	UNMANN	2.5	SMEF	0.49	0.075
00:00:03:51	1	2	REBELM	1	1	UNMANN	2.5	SMEF	0.49	0.075
00:00:03:53	1	2	REBELM	1	1	UNMANN	2.5	SMEF	0.5	0.069
00:00:03:56	1	2	REBELM	1	1	UNMANN	2.5	SMEF	0.5	0.069

B. SAMPLE TUVL DETECTION REPORT

GAME TIME	UNIT	SIDE	DETECTION SENSOR NAME	REPORT STATUS	UNIT	SIDE	NAME	STATUS	RANGE
00:00:02:01	5	1	UNMANN	MOVING, EXPOSED	50	2	REBELM	STATIONRY, DEFIL	0.258
00:00:02:04	2	1	UNMANN	MOVING, EXPOSED	11	2	REBELM	STATIONRY, DEFIL	0.137
00:00:02:22	2	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	STATIONRY, DEFIL	0.12
00:00:02:52	2	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	STATIONRY, DEFIL	0.099
00:00:03:04	6	1	UNMANN	MOVING, EXPOSED	53	2	REBELM	STATIONRY, DEFIL	0.052
00:00:03:22	4	1	UNMANN	MOVING, EXPOSED	28	2	REBELM	MOVING, EXPOSED	0.011
00:00:03:55	2	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	STATIONRY, DEFIL	0.065
00:00:04:58	2	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	MOVING, EXPOSED	0.039
00:00:05:43	2	1	UNMANN	MOVING, EXPOSED	11	2	REBELM	STATIONRY, DEFIL	0.022
00:00:01:22	4	1	UNMANN	MOVING, EXPOSED	29	2	REBELM	STATIONRY, DEFIL	0.106
00:00:01:22	6	1	UNMANN	MOVING, EXPOSED	53	2	REBELM	STATIONRY, DEFIL	0.113
00:00:02:22	1	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	STATIONRY, DEFIL	0.122
00:00:02:22	4	1	UNMANN	MOVING, EXPOSED	29	2	REBELM	STATIONRY, DEFIL	0.074
00:00:03:10	1	1	UNMANN	MOVING, EXPOSED	11	2	REBELM	MOVING, EXPOSED	0.155
00:00:03:40	2	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	STATIONRY, DEFIL	0.073
00:00:03:52	1	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	STATIONRY, DEFIL	0.069
00:00:04:34	4	1	UNMANN	MOVING, EXPOSED	28	2	REBELM	STATIONRY, DEFIL	0.044
00:00:05:01	4	1	UNMANN	MOVING, EXPOSED	29	2	REBELM	STATIONRY, DEFIL	0.004
00:00:05:01	4	1	UNMANN	MOVING, EXPOSED	32	2	REBELM	STATIONRY, DEFIL	0.239
00:00:01:46	5	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	MOVING, EXPOSED	0.441
00:00:02:01	3	1	UNMANN	MOVING, EXPOSED	29	2	REBELM	STATIONRY, DEFIL	0.137
00:00:02:07	2	1	UNMANN	MOVING, EXPOSED	11	2	REBELM	STATIONRY, DEFIL	0.137
00:00:02:07	3	1	UNMANN	MOVING, EXPOSED	46	2	REBELM	STATIONRY, DEFIL	0.385
00:00:02:40	2	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	MOVING, EXPOSED	0.111
00:00:02:43	4	1	UNMANN	MOVING, EXPOSED	28	2	REBELM	STATIONRY, DEFIL	0.054
00:00:02:43	6	1	UNMANN	MOVING, EXPOSED	53	2	REBELM	STATIONRY, DEFIL	0.061
00:00:03:07	2	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	MOVING, EXPOSED	0.09
00:00:03:40	2	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	STATIONRY, DEFIL	0.073
00:00:03:49	5	1	UNMANN	MOVING, EXPOSED	38	2	REBELM	STATIONRY, DEFIL	0.064
00:00:03:58	2	1	UNMANN	MOVING, EXPOSED	28	2	REBELM	STATIONRY, DEFIL	0.179
00:00:04:10	5	1	UNMANN	MOVING, EXPOSED	49	2	REBELM	STATIONRY, DEFIL	0.116
00:00:04:19	2	1	UNMANN	MOVING, EXPOSED	11	2	REBELM	STATIONRY, DEFIL	0.047
00:00:00:49	6	1	UNMANN	MOVING, EXPOSED	29	2	REBELM	MOVING, EXPOSED	0.318
00:00:01:13	6	1	UNMANN	MOVING, EXPOSED	53	2	REBELM	STATIONRY, DEFIL	0.12
00:00:01:22	2	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	MOVING, EXPOSED	0.162
00:00:01:22	2	1	UNMANN	MOVING, EXPOSED	4	2	REBELM	STATIONRY, DEFIL	0.324
00:00:01:43	2	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	STATIONRY, DEFIL	0.15
00:00:01:46	1	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	MOVING, EXPOSED	0.148
00:00:02:01	2	1	UNMANN	MOVING, EXPOSED	11	2	REBELM	MOVING, EXPOSED	0.137
00:00:02:01	3	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	STATIONRY, DEFIL	0.209
00:00:02:07	4	1	UNMANN	MOVING, EXPOSED	29	2	REBELM	MOVING, EXPOSED	0.086
00:00:02:37	1	1	UNMANN	MOVING, EXPOSED	1	2	REBELM	STATIONRY, DEFIL	0.11
00:00:02:43	4	1	UNMANN	MOVING, EXPOSED	28	2	REBELM	STATIONRY, DEFIL	0.054

APPENDIX E. PROBABILITY OF HIT TABLE

The probability of hit tables show range on the horizontal axis and single shot kill probability on the vertical axis. There are twelve plots, one for each shooter/target status combination. The first two letter describe the movement status of the shooter and target respectively as stationary (S) or moving(M). The third letter describes the protection of the target with a (D) or (E) that denote defilade or exposed respectively. More information is available in Reference 7.

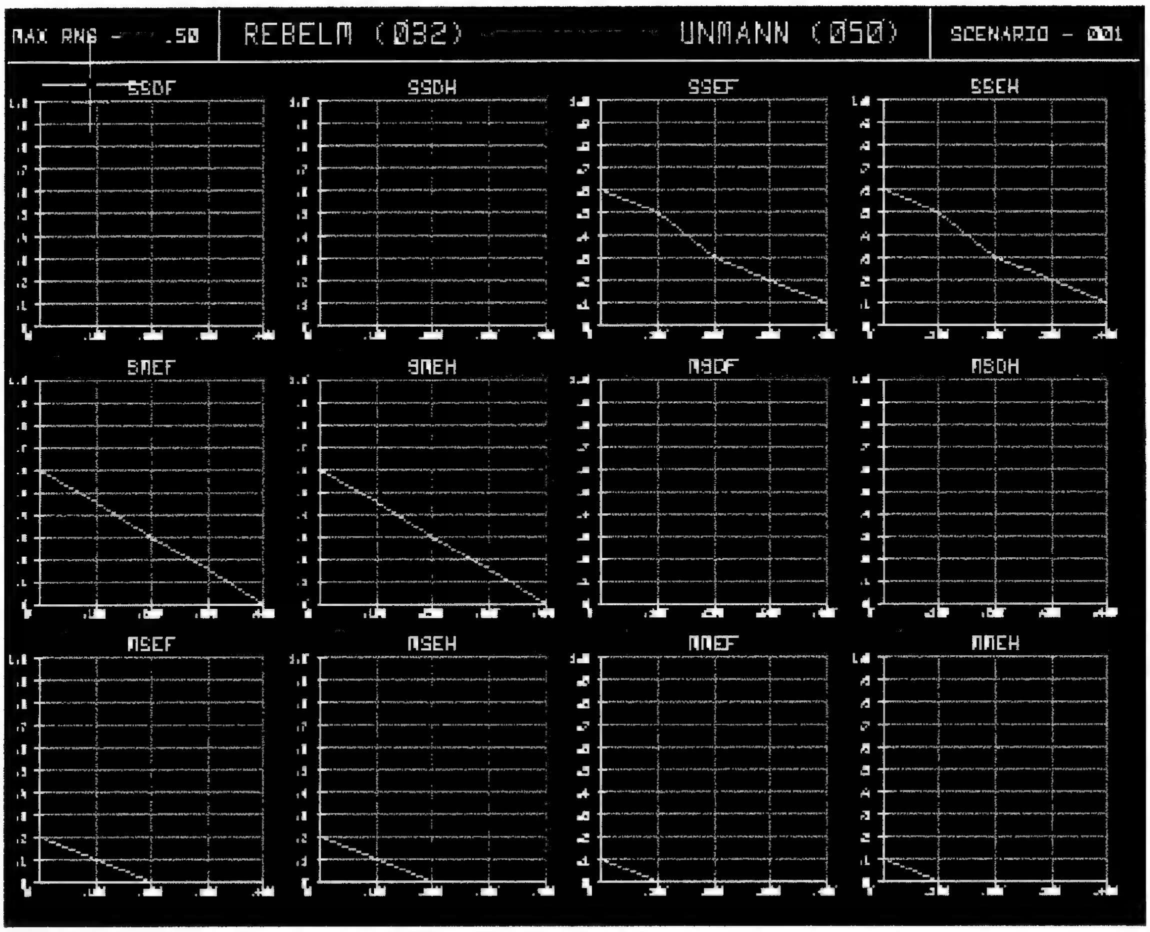

Figure 6. Probability of Hit Table

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APPENDIX F. STATISTICAL RESULTS

A. F TEST RESULTS FOR ZONE TO ZONE EQUALITY OF VARIANCE

Test Statistics

	tZone2	tZone3	tZone4	tZone5	tZone6
tZone1	1.817	1.246	1.021	0.684	1.438
tZone2		0.686	0.562	0.377	0.791
tZone3			0.820	0.550	1.154
tZone4				0.671	1.408
tZone5					2.100

Critical Values

	tZone2	tZone3	tZone4	tZone5	tZone6
tZone1	1.507	1.577	1.607	1.560	1.574
tZone2		1.513	1.545	1.495	1.510
tZone3			1.590	1.542	1.557
tZone4				1.562	1.576
tZone5					1.545

P-values

	tZone2	tZone3	tZone4	tZone5	tZone6
tZone1	0.002	0.171	0.466	0.949	0.058
tZone2		0.968	0.997	1.000	0.876
tZone3			0.804	0.996	0.262
tZone4				0.957	0.070
tZone5					0.000

Significance

	tZone2	tZone3	tZone4	tZone5	tZone6
tZone1	yes	no	no	no	no
tZone2		no	no	no	no
tZone3			no	no	no
tZone4				no	no
tZone5					yes

B. T TEST RESULTS FOR ZONE TO ZONE EQUALITY OF MEANS

Pooled estimate of the variance

	tZone2	tZone3	tZone4	tZone5	tZone6
tZone1	0.650	0.810	0.896	1.135	0.758
tZone2		0.590	0.642	0.847	0.551
tZone3			0.801	1.037	0.678
tZone4				1.128	0.748
tZone5					0.988

Test Statistic

	tZone2	tZone3	tZone4	tZone5	tZone6
tZone1	0.340	1.023	0.484	2.079	0.817
tZone2		0.980	0.298	2.407	0.694
tZone3			-0.498	1.294	-0.266
tZone4				1.625	0.272
tZone5					-1.555

Critical Values

	tZone2	tZone3	tZone4	tZone5	tZone6
tZone1	1.981	1.976	1.977	1.975	1.976
tZone2		1.972	1.973	1.972	1.972
tZone3			-1.976	1.974	-1.975
tZone4				1.975	1.976
tZone5					-1.976

P-values

	tZone2	tZone3	tZone4	tZone5	tZone6
tZone1	0.367	0.154	0.315	0.020	0.208
tZone2		0.164	0.383	0.008	0.244
tZone3			0.690	0.099	0.605
tZone4				0.053	0.393
tZone5					0.939

Significance

	tZone2	tZone3	tZone4	tZone5	tZone6
tZone1	no	no	no	yes	no
tZone2		no	no	yes	no
tZone3			no	no	no
tZone4				no	no
tZone5					no

C. POPULATION PROPORTIONS

1. ZONE TO ZONE EQUALITY OF PROPORTION DETECTED

Counts and proportions

ZONE	HIT	NOT HIT	TOTAL	P
1	71	116	187	0.380
2	118	134	252	0.468
3	80	228	308	0.260
4	70	231	301	0.233
5	87	190	277	0.314
6	81	209	290	0.279
TOTAL	507	1108	1615	

Test statistics

	Zone2	Zone3	Zone4	Zone5	Zone6
Zone1	-1.853	2.810	3.486	1.463	2.297
Zone2		5.135	5.827	3.635	4.552
Zone3			0.778	-1.453	-0.539
Zone4				-2.201	-1.303
Zone5					0.906

P-values

	Zone2	Zone3	Zone4	Zone5	Zone6
Zone1	0.968	0.002	0.000	0.072	0.011
Zone2		0.000	0.000	0.000	0.000
Zone3			0.218	0.927	0.705
Zone4				0.986	0.904
Zone5					0.182

Significance

	Zone2	Zone3	Zone4	Zone5	Zone6
Zone1	no	yes	yes	no	yes
Zone2		yes	yes	yes	yes
Zone3			no	no	no
Zone4				yes	no
Zone5					no

Simultaneous confidence intervals

ZONE	LOWER	UPPER	SIGNIFICANCE
1-2	-0.182	0.005	no
1-3	0.026	0.213	yes
1-4	0.053	0.240	yes
1-5	-0.026	0.159	no
1-6	0.007	0.194	yes
2-3	0.115	0.302	yes
2-4	0.143	0.329	yes
2-5	0.061	0.247	yes
2-6	0.096	0.282	yes
3-4	-0.066	0.120	no
3-5	-0.148	0.039	no
3-6	-0.113	0.074	no
4-5	-0.175	0.012	no
4-6	-0.140	0.046	no
5-6	-0.058	0.128	no

2. EQUALITY OF PROPORTION OF SHOTS THAT KILL

Counts and proportions

ASPECT	HIT	NOT HIT	TOTAL	P
FRONT	53	60	113	0.469
HULL	123	193	316	0.389
TOTAL	176	253	429	

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